Positioning System Shipborne Reference System

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LONG-TERM GOALS

The long term goad is to understand the error sources that dominate the navigation accuracy of a Global Positioning System (GPS) receiver on a ship. This information will then be used to design a system of receivers, auxiliary sensors, and data processing algorithms that can achieve a two meter position on ships using the current real time data coming from the GPS satellites. This system can then be used as a base station for differential GPS. This will increase the operational flexibility of the navy in carrying out many of its missions.

OBJECTIVES

The design of a system to improve on the current real time military accuracy of GPS requires an understanding of the characteristics of the various error components that limit the current system. The first objective will be to achieve this understanding in a quantitative way. Various means of overcoming these errors through averaging , use of auxiliary equipment and other information will be investigated and tested. The design, testing and validation of algorithms to implement a 2 m absolute shipborne GPS solution will be an objective.

APPROACH

Navigation using GPS in effect uses a pulsed timing system to find ranges to several satellites. To generate a position one must know the location of the satellites and have an accurate model of the satellite clocks. (Local user clocks are estimated along with the positions.) The current military user accuracy is dominated by the errors in the information broadcast by the satellites on the position of the satellite (ephemeris) and the satellite clock model. These are called the broadcast ephemeris errors. In at sea applications an equally important error is usually multipath, the reception of signals reflected from nearby objects and the sea surface. These are the principle errors that must be averaged down for this system to work. Of course, the motion of the ship will also complicate the this project.

This work will consist of both field work to collect data from shipborne experiments and laboratory analysis of that data. The data will be acquired on the RV PT SUR near shore in the Monterey CA area. Data out to 500 km from shore will be used. This data will be acquired in the Precise Positioning Service (PPS) or converted to PPS data in order to simulate what an actual military system would use. Both real time solutions generated inside the receivers and the raw measurements (pseudoranges and phases) will be collected for analysis ashore. The raw measurement data collected will not have its selective availability (SA) corruptions removed. This will be done later on shore in a Data Correction

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Facility (DCF). This allows the data on the research ship to remain unclassified, and still make the finial PPS data available for processing on shore in a classified environment.

The true position of the ship will be obtained through the use of Kinematic processing of data taken on the ship and shore. For this reason the ship must remain fairly close to the reference station during most of the experiments. This is done with Ashtech Z12 receivers and the Ashtech PNAV positioning program. This has been shown to have an accuracy of 10 cm out to 100 km. In tests done under this study there are strong indications that submeter accuracy is achieved out to a few hundred km.

A system might consists of:

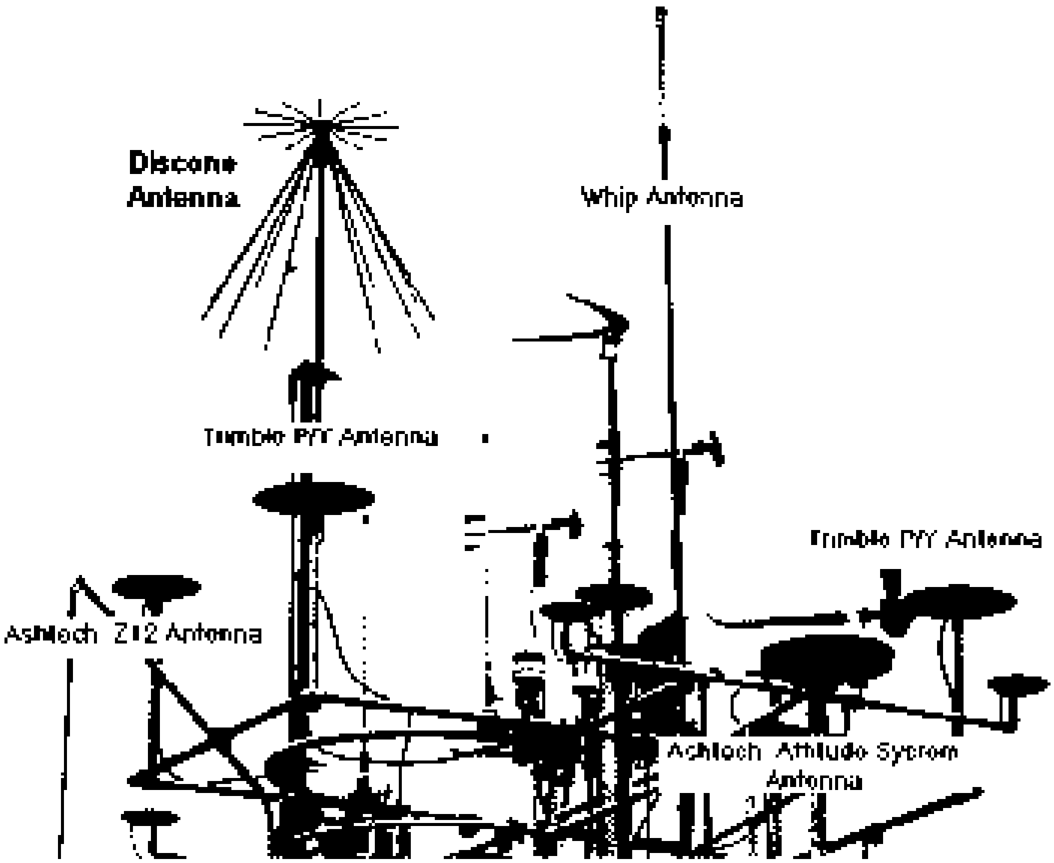
1. multiple antennas and receivers to use spatial averaging to reduce multipath,
2. an attitude system to assist in bringing together the data from multiple antennas,
3. atomic clocks to reduce dependence on the satellite clocks in the solution,
4. use of a precise geoid and antenna height to improve solutions,
5. software techniques using phase data to bring data at different times together, even on a moving platform,
6. software techniques to average many hours of data from many satellites to reduce the effects of broadcast ephemeris errors.

Experiments utilizing all of these elements will be performed using real data acquired at sea.

WORK COMPLETED

During the first two years of this project, three at sea experiments have been carried out. At the very beginning an experiment was performed using the small, single frequency, Precision Lightweight GPS Receiver (PLGR). This was followed by and experiment in July 1997 (GPS PT SUR 97) using dual frequency, geodetic receivers. In July 1998 GPS PT SUR 98 was fielded with similar high quality equipment. In both cases three or more attitude systems were used, one being a low cost inertial sensor. In PT SUR 97 a Systron Donner Motion Pack was used. IN PT SUR 98 a Crossbow unit. The hardware used in 1997 was mostly borrowed while that in 1998 was dedicated to this project. In addition this hardware was mounted in shock protected racks to make a ruggedized unit that could be used on a ship of opportunity.

PT SUR 97 consisted of two 4 day legs. There were 4 separate GPS receivers, each with its own antenna. The antenna were on a rectangular array 2 m by 3 m on the ship mast. Two of these receivers were the military version of the top of the line Trimble receiver. The other two were top of the line Ashtech receivers. On the first leg, the GPS experiment was not intended to be run due to conflicts with other experiments. A HF experiment had a large discone antenna in the middle of the GPS array (See Figure 1) . However this gave an opportunity to study a very high multipath environment, so the GPS equipment was turned on and collected data on this leg.



Antenna Array on PT SUR GPS 97 with Multipath Sources

GPS PT SUR 98 was and enhanced version of the earlier experiment. In this case 4 Ashtech ZFX receivers, Z12 receivers with a minimal operator interface, were used. These were all on a single atomic oscillator, being driven through a frequency distribution buffer amplifier. Three dedicated attitude units were used, a Crossbow 6 degree of freedom inertial unit, an Applied Geophysics tiltmeter, and a Precision Navigation TCM2 magnetometer/tiltmeter. In addition the vessel has a permanently mounted GPS based attitude system (Ashtech ADU2) and a Sperry gyrocompass.

RESULTS

From the PT SUR GPS 96 experiment [1] it was established that the broadcast ephemeris was the major error source in a ship underway. This error can be adequately modeled as a linear function of time, but not as a constant. The average effect of this error on horizontal position is about 4 m for each satellite. One key result was the disappearance of multipath error when the ship was underway. This is probably due the roll and pitch changing the relative orientation of the lines of sight of the satellites to the antennas and the multipath sources at a rate commensurate with the loop time constants in the receiver. However multipath is still a factor in dockside data.

Work on the establishment of a GPS Data Correction Facility is was completed late in FY 98. The data from PT SUR 97 was corrected for SA effects and a preliminary analysis performed.

Analysis of GPS PT SUR 97, even in the short time the corrected data has been available, has yield several results [2]. First the conclusion about ship motion reducing the effects of multipath was confirmed. Secondly, by comparing the two legs it was clear that multipath could still significantly affect GPS solutions on a ship. The horizontal real time solutions from the two PPS receivers was about 4 m on leg 1 and 3 m on leg 2 where the discone and TV antennas were removed. More significantly, the difference in these real time positions, after adjustment for the lever arm between then, was 0.6 m on leg 1 and 0.3 m on leg 2. This implies two things: first the fact that the difference was much smaller than the error means that the error was highly correlated, probably having its origin in the broadcast ephemeris. Second the fact that this difference was doubled in the leg with the extra multipath sources means that multipath does have a measurable effect at the 0.5 m level on a moving ship.

A software filter was designed to combine the range and phase data from both frequencies and separate the errors into various components. One of these components was the broadcast ephemeris error - the error expected to be the dominate one in military applications. There were 4 receivers on the ship and two on shore. Significantly the same broadcast ephemeris error was recovered from all 6 receivers. This shows that this error can be isolated at sea if a the ship's position is known at the meter level. It was also shown that quadratic fits to this error could reduce it to the 0.3 m level. A very simple filter was used to model the updating of a filter on an ongoing based from past measurements of this error. This showed that the ships position would be on the order of 0.3 m with 10 minute updates, 1.0 m with 30 minute updates and 2 m with one hour updates. With no updates this model statistically recovered the observed real time errors of the ship.

A summary of the significant results from the first two PT SUR GPS experiments follows:

1. The broadcast ephemeris error projected into the current user location can be recovered on a rolling ship at the level of the position knowledge of the ship antenna. This error is probably dominated by the satellite clock error, not positional errors.

2. Modeling of the broadcast ephemeris error with a linear function reduces the error to 0.7 m, with a quadratic to 0.3 m.

3. A very simple filter that assumes the orbit error is recovered at fixed intervals and treated as a constant can reduce its effect on the position error to 0.3 m with 10 minute intervals. More complex models are expected to achieve similar results with much longer sample times.

4. A quadratic model of a Rb atomic oscillator on a ship is adequate to reduce its effect on the position error to 0.3 m.

5. An attitude system with 0.5 deg of error or a drift in the range of 1 deg/hr is adequate for lever arm adjustments over a few meters with this system.

6. Multipath results

    a. Multipath on moving ships is reduced greatly by the ship motion.

    b. Multipath does have an effect at the 0.3 to 0.6 m level on position, depending on the severity of the sources.

c. The multipath from antennas separated by only 2 m is uncorrelated for PPS systems.

This work on the analysis of GPS PT SUR 97 is still rudimentary and the work with the 1998 data has not begun. With more analysis a full statistical characterization of the errors should be achieved and positioning algorithms designed that take into account the unique features and requirements of ships.

IMPACT/APPLICATIONS

Establishing a high accuracy position on a ship will enable it to serve as a Differential GPS reference station. This would be of value in precision targeting from airborne or ground assets. It would also be useful in mine warfare applications where navigation is extremely important in clearing mines, and in navigating known clear lanes. A force could sail into an area and begin work without establishing ground based reference stations on hostile territory. This work could also be useful to carriers in landing applications and other navy applications.

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